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ABSTRACT

The Information Age has been shaping the conception of thinking in education through the capability of computerized problem solving, through the resulting application of the information processing model to human thinking, and through the theories emerging from other cognitive science research in metacognition, construction of knowledge, and scientific inquiry. This paper is organized to provide background on the fragmentation of thinking and potential unifying principles underlying the possible integration of fragments. Topics covered are: (1) skills-oriented approach; (2) metacognition; (3) constructivist approach; and (4) scientific inquiry. In each topic, the content, history, assumptions, advantages, and issues are discussed. This paper summarizes recommendations of the New Jersey Basic Skills Council for those who make educational policy, those who construct or select instructional materials, and classroom teachers. (YP)

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TOWARD A UNIFIED CONCEPTION OF THINKING

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TOWARD A UNIFIED CONCEPTION OF THINKING

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INTRODUCTION

The Information Age has been shaping the conception of thinking in education through the capability of computerized problem solving, through the resulting application of the information processing model to human thinking, and through the theories emerging from other cognitive science research in metacognition, construction of knowledge, and scientific inquiry. The potential of these recent efforts may not be fully realized since most researchers treat -- and most of the literature reports -- these new ideas in isolation and approach global thinking abilities as fragmented skills that are distinctly different or mutually exclusive.

Current developments related to the conception of thinking appear to be vacillating between applying models derived from cognitive science research stimulated by the Information Age, applying models generated from school traditions of isolated disciplines, or applying memories of the good old days. Until recently the focus of thinking instruction has usually been on the imposition of discipline-specific models based on classical problem solving, traditional logic, and contrived issues (Sternberg & Martin, 1988). What seems to be emerging in different areas of educational research is a need to go beyond these models to facilitate students' search for, description of, and explanation of underlying principles and patterns, and to encourage students to integrate thinking about their thinking with knowledge that is worth thinking about. Risi (1982) pointed out that the creative, innovative, entrepreneurial spirit is dangerously low in Canada and the United States. This is clearly illustrated by the decline in the annual number of patent applications per researcher (p. 38). The United States Patent Office has initiated the Invent America project to discount this trend that is contrary to North America's economy needs for the 21st century, which stress innovations, development, and early production.

The impetus to question the traditional conception of thinking could have begun with the exhilarating but disconcerting claims regarding early artificial intelligence research made by Simon (1958):

> We now have the elements of a theory of heuristics problem solving and we can use this theory both to understand human heuristics processes and to simulate such processes with digital computers. Intuition, insight and learning are no

> longer the exclusive possession of humans; any large high speed computer can be programmed to exhibit them also. (p. 6)

Simon (1979), however, appeared to have made a further distinction between the human capabilities that could be simulated on a machine, and those that could not have been simulated, when he stated:

> If we are willing to regard all human complex problem solving as creative, then...successful programs for problem solving mechanisms that simulate human problem-solving solutions already exist and a number of their general characteristics are known. If we reserve the term creative for activities like discovery of the special theory of relativity or the composition of Beethoven's Seventh Symphony then no example of a creative mechanism exists at the present time. (p. 144)

The cognitive scientists' optimistic view about the possibility of replicating human thinking has not been fully realized (Beers, 1987). Computing capacity and processing speed have increased, but equally exciting breakthroughs in replicating human thinking from the machine metaphor have not occurred. Even though there have been advances in replicating human thinking with the development of SOAR, it is limited by having to be spoonfed the information it needs to solve particular problems (Wheeler, 1988). Cognitive science inquiries into problem solving have, however, produced conceptions of thinking that have brought into question establisned educational traditions and that have presented new challenges.

Stimulating thinking, in spite of the concerns expressed by Bloom (1987), Cheney (1987), and Hirsch (1987) will be education's logo of the 1990's. Costa (in Brandt, 1988) asserted "that the results are disappointing when we teach content alone in the hope that students will also learn to think" (p. 10). He also warned that "the teaching of thinking skills in isolation is just as unproductive" (p. 10). The information explosion and the ready access to massive quantities of information support the need for developing thinking that assesses the quality of the information (Munby, 1982; Roberts, 1983). Paul (1988) pointed out that it was important to promote critical thinking that encouraged people to think about their thinking as they are thinking to improve their thinking.

This symposium attempts to consider the following questions:

1. Do recently developed paradigms, such as cognitive science, metacognition, cognitive development, and interactive-constructive learning, help unify the fragmentation of thinking?
2. Can a unified conception of thinking be discerned from the literature and be operationally defined?
3. How can a unified conception of thinking be utilized to stimulate the development of thinking?

This paper is organized to provide background on the fragmentation of thinking and potential unifying principles underlying the possible integration of fragments. The symposium will attempt to outline potential pathways leading to unified conceptions of thinking and describe potential research

questions, instructional practices, and assessment techniques related to a unified conception of thinking.

BACKGROUND

The Information Age and cognitive science have appeared to encourage the increased proceduralization of the thinking process into microscopic, content-specific skills because of the reliance on the metaphor of the human mind as a computer and the use of machine heuristics for information processing as guides for the process of human thinking. This unique turn-of-events, which uses the computer to model thinking, has changed to using computers as models of human thinking and has had limited benefit. The machine metaphor has ignored the human affective dimension of thinking -- the emotional disposition, the risk taking, the curiosity, the self-confidence (Beers, 1987). Costa (in Brandt, 1988) suggested that thinking involves a wide variety of attributes, such as analytical, self-awareness, personal inclinations, ability to pose questions, clarify problems, monitor thought processes, and assess solutions. Garner (1987) also indicated that problem-solving strategies have cognitive, metacognitive, and affective components. Future projections regarding thinking range from Simon's hope to Smith's caution (in Brandt,1987):

> Any time you try to reduce teaching to a model you're in trouble, because models give us formulas, and formulas squeeze the life out of teaching. (p. 37)

Skills-Oriented Approaches to Thinking

Inquiry into thinking has consistently attempted to analyze and systematize the intellectual process into a list of microscopic procedures, objectives, envisioned goals, required skills, appropriate activities, stages, or steps rather than to discern macroscopic global patterns underlying transdisciplinary thinking (Sternberg & Martin, 1988). These proceduralizations have moved from the discernment of a common structure or pattern of inquiry, which is a progressive determination of a problem and its possible solution (Dewey, 1938, pp. 105-119):

1. The Antecedent Conditions of Inquiry: The Indeterminate Situation
2. Institution of a Problem
3. The Determination of a Problem-Solution
4. Reasoning
5. The Operational Character of Facts-Meanings
6. Common Sense and Scientific Inquiry

to early classificatory schemes like (Bloom, Engelhart, Hill, Furst & Krathwohl; 1956, p. 18)

1. Knowledge
2. Comprehension
3. Application
4. Analysis
5. Synthesis

6. Evaluation.

More recent attempts have produced curriculum prescriptions, such as the skills in a planning model of problem solving (Robinson, et al., 1985, p. 5).

1. State the problem as a question.
2. Clarify and reword the question.
3. Make a plan for answering the revised question.
4. Carry out the plan.
5. Record the data obtained to show relationships.
6. State relationships observed.
7. Interpret the relationships.

and the "Interdisciplinary Skills List", based on an information processing model (Robinson, et al., 1985, p. 5):

1. Establish a focus for the inquiry.
2. Develop a schema/framework for the focus.
3. Decode information at the source.
4. Determine adequacy of data.
5. Put data in the schema/framework.
6. Use a procedure to summarize data.
7. Observe relationships in data.
8. Interpret meaning of observed relationships.
9. Determine how the product applies beyond the inquiry situation.
10. Communicate the process or product of the inquiry.

These categorizations parallel the thinking-made-easy models, such as How to Solve it (Polya, 1957, p. xvi):

1. Understanding the problem.
2. Devising a plan.
3. Carrying out the plan.
4. Looking back.

The Complete Problem Solver (Hayes, 1981, p. 1-2):

1. Finding the problem.
2. Representing the problem.
3. Planning the solution.
4. Carrying out the plan.
5. Evaluating the solution.
6. Consolidating gains.

The Ideal Problem Solver (Bransford & Stein, 1984, pp. 11-21):

1. Identifying Problems
2. Defining Problems
3. Exploring Alternative Approaches
4. Acting on a Plan
5. Looking at the Effects

or De Bono's CoRT Tools model (in Melchior, Kaufold & Edwards, 1988, p. 33):

1. CAF: Consider All Factors
2. FIP: First Important Priorities
3. PMI: Plus, Minus, Interesting Points
4. C+S: Consequence and Sequel

5. AGO: Aims, Goals and Objectives
6. APC: Alternatives, Possibilities, Choices
7. OPV: Other Points of View

Most of the procedural lists of skills, stages, or steps appear to arise from the persistent perception that "the nature of the problem fixes the end of thought and controls the process" (Dewey, 1933, p. 15), that "human problem solving is basically a form of means-end analysis that aims at discovering a process description of the path that leads to a desired goal" (Simon, 1979, p. 223), and that "human beings seem to need to break complex problems into component parts in order to succeed" (Bransford & Stein, 1984, p. 19). Inquiry in the 17th, 18th, 19th, and 20th centuries has been productively driven by the reductionist view, but there is an increasing awareness of the need to move beyond the reductionist model into exploring unifying principles and patterns.

Educational theorists who generate lists appear to be making a series of implicit assumptions. They appear to be assuming that the idea, event, or thing is decomposable when, in fact, it may not be. They may be assuming that the listed components equal the whole -- a model originally derived from traditional mathematics and then extended unsuccessfully to other disciplines. Generators of the lists may also be assuming that the lists will be interpreted in the same manner in which they were generated. Unfortunately, the complexity of the analysis and the subtlety of thought that gave rise to these lists may be lost in the process. In addition to these assumptions, there are two psychological assumptions that have formed the foundation for concepts about the thinking process, specifically (1) "the central nervous system is basically organized to operate in a serial fashion" and (2) "the course of behavior is regulated or motivated by a tightly organized hierarchy of goals" (Simon, 1979, p. 30).

These assumptions are not usually made explicit to the users of lists about thinking. Although the procedural thinking categories of skills, stages, and steps are usually conceived by the generator as being only guidelines or suggestions, frequently lists are perceived by the users as a definitive locus of points; and they bestow on the lists an aura of rigorous event seriation, of mutual exclusiveness, and of exhaustiveness. This dogmatic obedience may result in each component being isolated and followed sequentially in the belief that the desired whole will miraculously reappear. The users reify and glorify the list and impose the component categories with fervid dedication on their thinking. Often, as a result of the reification of the lists, the users become compelled not only to rigorously adhere to the sequence but also to slavishly follow the full sequence. Lists are usually in numerical, hierarchical, or acronymistic forms, which reinforce the perception of definiteness. There is something inexplicably hermetic about numerical, hierarchical, or acronymistic lists; people perhaps believe the revelatory implication that the key, the explanation, the truth, or the underlying principle is embedded in the lists. All of these pitfalls of lists can be seen in terms of the mechanistic interpretation of the scientific method. The singular article -- the -- is interpreted as the one and

only and the features of the method are interpreted as a linear series of lockstep points.

Procedural lists contribute not only to the perception of the decomposability and the definiteness of the thinking process but also to the illusion of the simplicity, the determinability, and the controllability of the thinking process. Numerical, hierarchical, and acronymistic lists of the thinking process appear to offer a simple procedure to what is a complex process and to ensure productive engagement. The productive engagement appears to be more effective when applied to well-structured, school problems rather than real-life problems (Sternberg & Martin, 1988). Although it is important not to conceive of the thinking process as an unfathomable mystery, it is still equally important not to minimize the incredible complexity of the thinking process.

Lists also create the illusion of determinability by giving the impression that it is possible to determine with some degree of certainty the sequence of procedures required for productive thinking. The illusion of controllability follows the impression of determinability. The illusion of controllability inherent in the lists may have arisen because of the impression of the uncontrollability of the consequences resulting from engaging in the thinking process. Goldman (1984) warned of the risk associated with uncontrollable consequences of true inquiry in the classroom:

> If the goal of schooling is achieved outside the formal setting, then measurement and evaluation lose their importance, if not their very being. Teachers lose their accountability. Students are no longer viewed as material to be manipulated or managed, and the conclusions of their thinking cannot be monitored. Outcomes of student thinking may be unpredictable and may never even be known to the teacher or school, as behavioral objectives for students are transcended. But isn't that what happens when there is true inquiry, when we follow the argument where it leads? (p. 62)

Goldman's loss of power is a risk masked by many procedural lists, but a risk well worth taking, since the gain is so great -- thinking. The illusions of simplicity, determinability, and controllability appear to be the antithesis of the process of thinking.

The intellectual distillation of thinking has divided thinking not only into procedural lists but also into category types. The literature on thinking in education specifically mentioned reflective thinking, critical thinking, creative thinking, dialectical thinking, reactive thinking, inventive thinking, divergent thinking, convergent thinking, logical thinking, lateral thinking, rational thinking, scientific thinking, and mathematical thinking. Each category often has its own sub-set of procedures. Beyer (1988) identified types of thinking and related sub-sets of procedures: (1) problem solving (five thinking strategies), decision-making (six thinking strategies), and conceptualizing (six thinking strategies); (2) Critical Thinking Skills (ten critical thinking skills); and (3) Information Processing Skills (nine information processing skills). This partitioning may be counter-productive and likely does not reflect reality. It is unlikely that thinkers use a straight transmission approach to their thinking. They do not select a specific intellectual gear to start thinking, a higher gear to

creatively think, or a reverse gear to deductively verify their inductively generated constructs. This compartmentalization of thinking is likely reinforced by the box-like, discipline-based curriculum of traditional schools. It is unlikely that integrated learning organized around issues and problems would promote compartmentalized thinking. It is more likely that Science-Technology-Society oriented curricula require an automatic transmission model of thinking, where the demands of the task are monitored and adjustments are made accordingly. Risi (1982) pointed out that many of the most exciting scientific problems currently cross traditional science and thinking boundaries. Aikenhead (1980) clearly demonstrated the need to embed scientific and technological inquiries into a societal context. The scientific and intellectual purity once valued has less potential in 21st century problem solving. Winkler (1987) indicated the extent of the interdisciplinary challenge:

> Some scholars...say those 'blurred genres'...represent a fundamental shift in the way we think: a change not just in where we draw intellectual boundaries but also in how we draw them (p. A 1). ...The development of interdisciplinary research in this century has been driven by a growing conviction that important questions about nature and society can no longer be neatly divided among the disciplines. (p. A 14)

One factor that has given additional momentum to the decomposition of thinking into lists of sub-routines and skills is the current emphasis on accountability, assessment, and time constraints. Valid assessment of thinking may not fit into the traditional test format. Procedural lists in thinking encourage the use of well-structured problems and rationalize the use of standardized examinations, because each sub-routine and skill can be tested independently and test items can be self-contained (Sternberg & Martin, 1988). Unfortunately the sum of these items may not equal the global task being assessed -- real-life thinking involving ill-structured problems. Standardized tests with emphasis on selected responses by necessity require a simplistic view of thinking and must be limited to solvable problems. Standardized examinations provide no time to ruminate over experimental methods arrived at through extended periods of contemplation and interaction or to involve informal knowledge characteristic of real-life problems. A combination of continual practice with these test items and the entrenchment of well-established procedures reflected in sequences of skills, steps, and stages will probably increase test scores. The increased test results, however, do not likely mean improved thinking has occurred.

Advocates of the importance of stimulating thinking within the educational system often justified the inclusion of teaching for thinking in the school curriculum by attempting to demonstrate that teaching thinking improves academic test scores. Worsham and Austin (1983) appear to have justified the existence of their program in that it "produced significant gains in SAT scores" (p. 70). Similarly, Zenki and Alexander (1984) justified the implementation of a "Thinking Skills Program" by claiming that their program was "part of a broad and comprehensive plan to improve student achievement in an area characterized by low student scores" (p. 81). These justifications of teaching

thinking are riddled with shortcomings. Marzano and Costa (1988) found after analyzing the Stanford and CIBS achievement batteries that the test items include only 9 of the 22 general cognitive operations that they isolated. Tests appear to assess students' ability as a repository of information -- an ability that is almost redundant in the Information Age. De Bono (1985) also appeared to perceive the limitations of traditional tests, when he stated:

> Being a thinker does not involve being right all the time. Indeed, anyone who is right all the time is likely to be a poor thinker (arrogant, uninteresting in exploration, unable to see alternatives, etc.). Being a thinker does not involve being clever. Nor does it involve solving all those cunning problems that people always expect one to solve. Being a thinker involves consciously wanting to be a thinker. (p. 18)

Even the former U.S. Secretary of Education (Bennett, 1988) corroborated the limitations of traditional tests when he stated that "tests that allow for guesswork, provide no measure of ingenuity or thinking skills" (p. A 36). It could likely be demonstrated that teaching thinking does not improve traditional test scores because students might not be satisfied with simplistic answers. Lipman (1984) acknowledged the impact of testing results on the development of thinking programs when he stated:

> As the suspicion becomes widespread that the disappointing academic performance of a great many students is connected with a short fall in cognitive skills, advocates of some disciplines have begun to take an interest in the situation. We have found, for example, that the mean scores of college freshman are less than one point above the mean scores of sixth grader on the New Jersey test of reasoning skills. (p. 51)

The decision to emphasize stimulation of thinking in the school curriculum should not become subservient to the overriding necessity to succeed on traditional tests. It has been well established that assessment drives curriculum and instruction, which in turn drives learning -- what is tested, is what teachers teach to and students study for. If the thinking process involves reflection, contemplation, incubation, and exploration into resolvable, not necessarily resolvable and unresolvable problems, then assessment devices must be developed to measure actual thinking.

Sigel (1984) presented the thinking-as-a-means-to-improve-tests model for the 1980's:

> The educators' double bind for the 80's is the necessity of developing children's representational competence through reflection, discovery and inquiry, while also producing effective test scores likely to result from didactic teacher-centered strategies. (p. 21)

This double bind is only a problem if educators continue to use traditional means of assessment based on the fact-acquisition model. The lack of a clear, concise, unified conception of thinking and the lack of an operational definition of thinking may have contributed to the problem.

Metacognition

Jacobs and Paris (1987) suggested metacognition is a global construct "that refers to thinking

about thinking" (p. 255). Metacognition focuses on knowledge about strategic planning, managing action and monitoring the task. Much exploration of metacognition has been focused on the reading task. Unfortunately, this has led many educators to classify metacognition exclusively as a reading construct; but metacognition appears to be equally applicable to the thinking process, problem solving, decision-making, and scientific inquiry as it is to language acquisition. Piaget and Vygotsky provided much of the foundation to support this inference. Again, unfortunately, many educators focus on the differences rather than on the similarities between Piaget's and Vygotsky's models (Wertsch, 1979). Piaget's emphasis on experience and internalized restructuring (thinking) is not contrary to Vygotsky's language (speech) as a tool to complex thinking. The issue is not whether language or experience is more important but rather when or where experience and language occur to promote and facilitate thinking. Situations rich in language, activity, and social interaction that engage people, provide appropriate concrete experience, and encourage people to predict, organize, synthesize, verify, and restructure their understanding are the most effective learning and thinking situations (Anderson & Smith, 1987; Yore, Beugger, Romance & Shymansky, 1986). Wood (1980) suggests that effective teaching/learning rests on a close relationship between language and action; neither are adequate by themselves. Language must be interwoven with activity; at times language leading activity and at other times activity leading language but always interdependent and always stimulating thinking. The potential of metacognition's role in a unified conception of thinking will need to be based on reading research to reveal generally applicable thinking attributes since little metacognition research exists in other subject areas.

Historically, metacognition has evolved from people's knowledge about tasks, people, and strategy variables (Flavell & Wellman, 1977); to people's sensitivity and to ways people orchestrate their thinking (Flavell, 1979); to executive strategies such as planning, monitoring, revising, and repairing understanding internally and externally (Brown, Bransford, Ferrara & Campione, 1983). Baker and Brown (1984) pointed out that "two not necessarily independent clusters are included in metacognition: knowledge about cognition and regulation of cognition" (p. 353). Jacobs and Paris (1987) defined metacognition as:

> any knowledge about cognitive states or processes that can be shared between individuals. That is, knowledge about cognition that can be demonstrated, communicated, examined and discussed. Often, metacognition is exchanged verbally or used privately but, for us, the essential defining feature is that metacognition can be made public. Thus, it is reportable, conscious awareness about cognitive aspects of thinking. (p. 258)

This definition was driven by assessment motives, which increase the validity and reliability of the construct. Jacobs' and Paris' definition ensures consciousness and deliberate reasoned judgment -- essential conditions for any unification with scientific inquiry that is also a public event. Furthermore, temporary lack of awareness and automatic skills can be returned to metacognitive

status as the difficulty of a task demands the transaction or when a thinker is requested to provide a justification or rationale for specific actions.

Jacobs and Paris (1987) decomposed metacognition into two broad categories, each with three sub-categories (figure 1). Jacobs and Paris stated:

> The appraisal of thinking can be one's abilities or knowledge, or it might involve an evaluation of the task or consideration of strategies to be used. ... Declarative knowledge refers to what is known in a propositional manner. ... Procedural knowledge refers to an awareness of cognitive processes of thinking. ... Conditional knowledge refers to an awareness of the conditions that influence learning. ...
>
> Self-management refers to the dynamic aspects of translating knowledge into action. Three types of executive processes can encompass the activities of self-regulated thinking. ... Planning refers to the selective coordination of cognitive means to a cognitive goal. ... [Thinkers] can evaluate their understanding as they pause, paraphrase, answer questions, or summarize information. Evaluation of thinking is an ongoing process in any domain. ... Regulation requires an individual to monitor progress and then revise or modify plans and strategies depending on how well they are working. Self-regulation allows the [thinker] to adjust, to changing task demands as well as to successes and failures. (pp. 258-259)

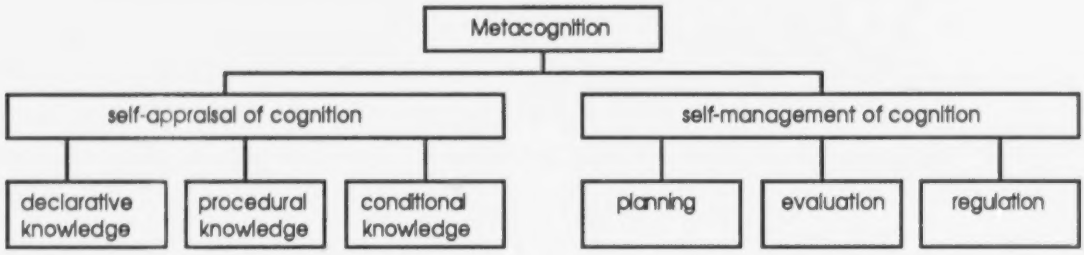

Figure 1: Metacognition (Adapted from Jacobs and Paris, 1987)

Paul's (1988) thinking about your thinking as you are thinking to improve your thinking is metacognition. Baker and Brown (1984) stated "the ability to reflect on one's own cognitive processes, to be aware of one's own activities while reading, solving problems, and so on, is a late-developing skill with important implications for the child's effectiveness as an active, planful learner" (p. 353). Being mindful and being metacognitive are goal-oriented aspects of thinking that are amenable to instruction (Paris & Oka, 1986).

Bransford (1979) developed an interactive model to describe learning and to illustrate the tasks involved, the factors influencing success, the cognitive processes embedded, and the metacognitive strategies required to manage the global process. Holliday (1988) slightly modified the model to illustrate its value in describing science understanding (figure 2). Critical tasks are the

learner's/thinker's goals; characteristics of the learner/thinker are the personal attributes influencing task performance; cognitive and metacognitive activities are the active construction or modification of understandings and monitoring, applying and fostering of the learner's/thinker's thoughts; while nature of the situation involves the characteristics of the information, its presentation, and other situational variables.

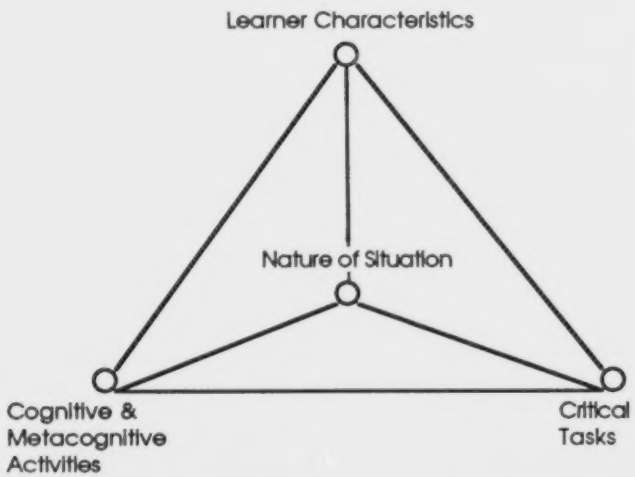

Figure 2: Tetrahedral Interactive Model (Holliday, 1988)

The tetrahedral model illustrates the interactive lines, planes, and spaces of the four foci. Thinkers must interactively process information by instantaneously switching back and forth between selective perceptions of presented information on the one hand and by comparing the information with their personal recollections on the other hand (Holliday, 1988). Learners/thinkers increase or change their understanding by extracting information from the situation (text, charts, pictures, other people), called bottom-up processing; by retrieving information from their memory and deciding what should be considered, called top-down processing; while monitoring, strategically planning, assessing, and evaluating the global interactive process. Thus, cognition is an interactive-constructive process and metacognition is a conscious consideration of this interactive process, which results in verifying, structuring, and restructuring information into meaningful understanding-knowledge networks called schema. The success of establishing valid factual nodes in the knowledge network and associated linkages between nodes determines the success of the learning, the applicability of schema, and the retrievability of the understanding from long-term memory. Future understanding depends on the variety, richness, and organization of prior experience and that the prior knowledge is stored in and readily retrieved from these schema.

The critical task in education involves the construction of meaningful explanations for patterns of events that were revealed by the exploration of the events and descriptions of the patterns. This task frequently requires thinkers to orchestrate their cognitive processes and knowledge structures toward abstract, difficult, and complicated goals focusing on relevant critical knowledge while restructuring this knowledge in terms of their prior knowledge. How successful this process is depends on the degree of meaningfulness and the learners'/thinkers' metacognitive strategies used in the process (Novak, 1987). Knowing about meaningful learning and knowing about the structure of knowledge empowers learners/thinkers to take charge of their learning/thinking. Novak and Gowin (1984) utilized concept mapping to improve thinkers' understanding of how concepts are inter-related and fit into hierarchies and that knowledge organized into large integrated and related chunks is easier to store and retrieve from long-term memory. Knowledge about how concepts are developed and attained, the value of supporting examples and non-examples, and how compare/contrast analysis is utilized to invent concepts can improve learning and clarify thinking. Novak (1987) suggested these strategies help thinkers to realize that concepts are constructed from perceived patterns of regularities and language or symbolic labels are used to communicate these regularities. Furthermore, thinkers must realize that knowledge claims frequently carry associated value claims; and they must be able to discriminate between these claims. Declarative knowledge, procedural knowledge, and conditional knowledge about the general structure and construction of knowledge often are not considered as critical as content specific prior knowledge.

The effectiveness of thinking and learning is also related to the access of specific prior knowledge directly related to the task. Novak and Gowin (1984) stressed the importance of accessible knowledge, while Sternberg & Martin (1988) stressed the importance of both formal and informal knowledge. Few people would question the importance that a sound knowledge foundation has on effective thinking, but one must realize that prior knowledge about the specific task is a necessary component while not being a sufficient component.

When the metacognitive theories are applied to education, a new set of lists appears to emerge. For example, Brown (1980) outlined active reading strategies that result in comprehension, which might equally well apply to thinking:

a) clarifying the purposes of the task(s);
b) identifying the important aspects:
c) focusing attention on the major content rather than on trivia;
d) monitoring ongoing activities;
e) engaging in self-questioning to determine whether goals are being achieved; and
f) taking corrective action when and where needed.

Gavelek and Raphael (1985) outlined what they perceived as an "information-processing analysis of questioning and comprehension":

1. Students must first be sensitive to problems that they are experiencing in comprehending a given unit of text.
2. There must be an accurate characterization of this state.
3. Someone must determine the correct source(s) of information necessary for answering this (these) question(s).
4. This (these) source(s) must be searched so that the information is adequately retrieved and integrated.
5. An answer must be constructed.
6. This answer must be compared to some criterion to determine its adequacy. (p. 11)

Holliday (1988) summarized the metacognitive literature to generate a list of general characteristics of metacognitive strategies of good learners/thinkers:

1. They understand the need to focus on the tasks, work hard, allocate time, generate enthusiasm and be responsible for their independent success.
2. They understand that comprehension is different than merely recalling or applying rules.
3. They decode presented information in a rapid, accurate, automatic fashion. Little conscious thought goes into most decoding, but consciousness is activated when difficulties arise.
4. They effectively test hypotheses generated by processing information and comparing the information with their own schema. They check the plausibility of their interpretations and continually re-evaluate and refine presented and stored information. They build hypotheses and assess the meaning of what they are doing in relation to their learning goals.
5. They understand the need to depend more on their bottom-up processes when reading science texts than when reading for pleasure.
6. They recall and comprehend important information, such as that contained in topic sentences and in text headings, rather than trivia unrelated to learning goals.
7. They solve problems by spending time and effort planning and performing task analyses, while allocating reasonable mental resources. They are sensitive to feedback information.
8. They use their learning materials wisely by capitalizing on competent text, information sources and teacher resources.

Barr, Blackowiez, Johnson, Morris, Mosenthal and Ogle (1987) stated:

> Metacognition is a matter of awareness, monitoring, and compensation. Somehow, though transparent individually, these parts of metacognition seem opaque when trying to understand the whole that they define. The discreet, linear, chronological connotation of saying 'metacognition is awareness, monitoring, compensation'; betrays the extent to which awareness, monitoring, and compensation interpenetrate, interact, and are simultaneous with one another in characterizing a whole greater than themselves. (p. 213)

This global intellectual function is equally apparent in reading, writing, listening, speaking, problem-solving, decision-making, and inquiry. Each component of metacognition is woven into the fabric as a continuous, multi-colored thread of combinations of awareness-monitoring-compensation. Whereas monitoring involves making and verifying predictions and inferences, forming and testing

hypotheses, and building, completing, and modifying schema (Baker & Brown, 1984). Awareness involves both an emotional disposition and an intellectual alertness regarding the focus of the task and the progress of the endeavor. While compensation involves the modification of a plan, fixing-up of the inference or hypothesis, or restructuring of prior beliefs in situations of dissatisfaction. De Bono (1985) developed a specific blue hat in his thinking hats metaphor for this executive thinking function. He cautions that his six task specific colored thinking hats had been developed because of considerations external to thinking, i.e., ease of training, personal security, and signaling within the discussion. De Bono implied that each color runs into the next and the blue color of executive thinking crosses all color boundaries to produce a technicolored thinking hat.

Constructivist Approach

Constructivism is a concept that has been used in several disciplines. Its origin appears to be in art, in which it appeared to be related to a new conception of reality. Constructivism in art was crystalized later to be:

> The deliberate use of reality to underline the artists' conviction that what they were doing in their abstract paintings and constructions constituted a new reality, a Platonic reality of ideas and forms more absolute than any imitation of nature. Artists would no longer imitate, modify or expand on optical reality or nature but they would be called upon to construct their own reality (Arnason, 1968, p. 224).

In Philosophy, Constructivism has appeared in many contexts. One context was described by Lorenzen (1987) as a process that accepts:

> as meaningful only those procedures and propositions that can be demonstrated to be constructible from a foundation in non-linguistic procedures and similarly founded linguistic operations by us. ... The construction has to be done methodically, that is step by step without gaps and without circles. ... The act of thinking is a human production; if we inquire into its method we then need to understand this method as a human production tool. We understand nothing so well as that which we could also make if we were given the necessary material. (pp. 4-18)

The power of invention and construction is founded in improved insight and increased clarity. The artists believed it was possible to achieve greater insights by constructing a personal reality rather than trying to copy reality. The philosophers realized that increased understanding is associated with the crafts of inventing and constructing and with personal involvement.

The psychological use of the constructivist paradigm was based in Piaget's Structuralism (1970), To Understand is to Invent (1976), The Construction of Reality in the Child (1977); Piaget's and Inhelder's The Psychology of the Child (1969), and The Child's Construction of Quantities (1974); and Inhelder and Piaget's The Growth of Logical Thinking from Childhood to Adolescence (1958) and The Early Growth of Logic in the Child (1959). In these books and others, a cognitive development

model described how children interact with the real world and utilize their conservation abilities, logical groupings, infra-logical groupings, internal structure, and formal operations to invent a personal image of reality. The cognitive development model involves three major components: the sequential stage development of people's intellect, the internal intellectual structures of the thinker, and the general mechanism governing the process. Much early research in education was devoted to clarifying, specifying, and assessing the internal structures and stages. Later, some effort has been devoted to the general conception of the model and the governing mechanism.

The cognitive development model assumes that individuals pass through a fixed series of developmental stages with each stage having associated intellectual abilities. The stages were sensori-motor, pre-operational, concrete operational, and formal operational. Many misconceptions were associated with the stage model such as assigning specific ages to each stage, assuming all people would reach the final stage, and suggesting that teaching should attempt to accelerate the transitions between stages by focussing on the specific intellectual tasks related to each stage.

Internal cognitive development structures describe the logico-mathematical abilities, operations, and processes used in solving specific problems. These structures were associated with specific development stages. Much of the work of the early researchers was motivated by the desire to specify standard tasks, to describe performance and to infer underlying mental functions with little or no concern for how these functions were used in real life thinking.

Conservation abilities relate to an individual's ability to recognize and to rationalize the invariance of specific quantity while other attributes are physically distorted (Yore & Ollila, 1984). Frequently the importance of the explicit logical necessity, compensation, or reversibility propositions in the rationale were overlooked and the greatest emphasis was placed on the selection of the invariant option regarding the apparent change in quantity. The onset of conservation abilities means the child has likely attained a consistent logic rather than a logic of convenience and likely the child has developed the intellectual foundation of rule formation.

Logical groupings consider the thinker's classification and seriation abilities of objects and events. The eight logical groupings break down into two parallel series of four abilities; one set dealing with classes and the other set dealing with relations. These abilities and related fundamental assumptions dealing with establishment of classes, identification of relationships, subordinate and superordinate classes, compare/contrast analyze, and rule discernment and application. These logical grouping abilities represent fundamental critical thinking skills, but little research has explored the relationship between classification and seriation tasks and complex thinking.

Infra-logical groupings deal with the child's conception of space and time. The space groupings are specifically directed towards topological space, Euclidean space, and projective space. Other

infra-logical groupings deal with time and measurement. Direct relationship between the attainment of specific infra-logical groupings and complex thinking has received little attention, even though direct implications to space-time problems are apparent.

Attainment of the logical and infra-logical groupings is spread over childhood to adulthood for many people. The implication that these abilities were concurrent with the concrete operational stage and preceded the formal operational stage have not been supported by many studies.

Formal operations deal with combinatorial, correlational, probablistic, and separation of variables abilities. The formal operational generally operate on other operations in an executive function. They hold a metacognitive relationship to the earlier cognitive development abilities. It is these formal operations that allow a thinker to consider what might be rather than just what is, go beyond prior experience, and not be limited by real world boundaries.

Lawson, Karplus, and Adi (1978) described formal operations much like hypothetico-deductive inquiry (Morine & Morine, 1973; Yore, 1980), in which a thinker can generate a tentative causal relationship, predict outcomes based on the assumptions the hypothesis is true and false, and to use the hypothesis as a blueprint for planning and executing a verifying test. This sequence of events closely parallels the conceptual change model (Anderson & Smith, 19787). Lawson and Thompson (1986) found that students who possessed formal operations held fewer science misconceptions than non-formal operational students. They claimed the reason for less misconceptions was that the formal operational students possessed the reasoning patterns necessary to overcome prior misconceptions. Good, Renner, Lawson, and Abraham (1988) illustrated how the inclusion of a prediction phase in the learning cycle clearly involves a greater degree of formal thinking than did the original explore, invent, and apply learning cycles. Furthermore, the revised learning cycle more closely parallels hypothetico-deductive inquiry.

Yore, Collis, and Ollila (1988) summarized many concerns regarding the unimpressive research trends between cognitive development abilities and early school achievement in reading, writing, mathematics, and science. Most of the studies considered attempted to associate performance on one or a few cognitive development tasks with specific school achievement. Kuhn, Ansel, and O'Loughlin (1988) described criticism of the cognitive development model on logical and empirical grounds. They suggested there are serious inconsistencies and anomalies in the logical construction of the model, and research results do not support the structural unity of the model.

Unfortunately most cognitive development related research may be missing the most important element in the model -- the mechanism governing the invention/construction of knowledge. Gallagher (1979) encouraged researchers to explore the biological interpretation of Piaget's model in a global sense rather than as discreet individual tasks. Arlin (1981) criticized much of the early research as utilizing an insufficient or inappropriate battery of tasks to fully represent the equilibration process.

The assimilation and accommodation involved in equilibration can be related to routine reinforcement learning, in which new knowledge is integrated into existing schema, and to more difficult conceptual learning in, which schema must be constructed or reconstructed. The ability to perform cognitive development tasks may only be a tangential indicator to these mechanisms. Yore, Collis, and Ollila (1988) reported that significant correlations with grade one reading, writing, and mathematics were found when a global assessment of cognitive development using a multi-variate regression approach was used. They believed that the global measure may be an indication of the child's ability to re-establish equilibrium rather than any specific cognitive ability.

Karplus (1970) and Shymansky and Yore (1980) encouraged the development of teaching/learning strategies that stressed problem identification, experience, invention, and application that closely paralleled equilibration. The addition of a prediction phase to the learning cycle may add power to an effective approach in that it will promote formal operations (Good et al, 1988). The hypothetico-deductive inquiry added to structured inquiry and semi-deductive inquiry may have the same global effect (Yore, 1980).

The constructivism model of thinking and learning has focussed more on the global invent/construction mechanism than on individual tasks. It appears that the consideration of the experience, social interaction, and equilibration (assimilation/accommodation) process is a much more promising representation of how knowledge is created and the barriers to effective thinking.

Sameroff (1983) referred to constructivism as a selective process much as scientists use scientific theories to select certain facts as more relevant than others and to impose on observation rather than to be determined by observation. Sameroff went on to clarify constructivism when he stated:

> It is not implied here that scientists make up theories which have nothing to do with facts but rather that there is a reciprocal relationship between theory and facts in which both have an inseparable role. This transactional position -- in which what the scientist drives is strongly influenced by what theory is held and at the same time what theory is held is strongly influenced by what facts are observed -- is analogous to what has come to be called the 'constructivist' position in developmental psychology (Piaget, 1970). Constructivism when applied to understanding psychological development focuses on the active role of children in creating their cognitive and social worlds. ... [The] basis of constructivist theories such as Piaget's in Psychology, is not that children construct a representation of the world but rather that, through their constructive ability, they build themselves. (p. 266)

The constructivist approach appears to be compatible with the notion that the brain is a model builder and its central function is to construct a model of reality. Wittrock's (1981) generative model suggested:

> That readers generate meaning as they read by constructing relations between their knowledge; their memories of experiences and the written sentences, paragraphs and passages. ... [to] comprehend a text, we not only read it, in the nominal sense of the word, we construct a meaning for it. [In general] to

> comprehend written language we must do more than read it, and more than construct a meaning for it. We must devise the constructed or reconstructed meaning or meanings from the syntactic and semantic characteristics of the written language that we read. ... In the generative model, we incorporate the previously introduced common core of psychological processes of reading comprehension and we expect to find a variety of currently unknown processes used differently by different people, depending upon the context, the reader's intentions, places, expectations, purposes, knowledge and experiences. ... [The] generative model implies that learners construct word meanings as well, again using context and other cues in the process. (pp. 229-231)

One outcome of the application of theories of constructivism to education is the realization that young thinkers do not come to a problem situation with a *tabula rasa* (Driver, 1983). Furthermore, if students are actively constructing reality and their previously constructed reality is actively influencing the construction of their new reality, then educators must find a way of modifying the previously constructed reality, if this reality does not correspond to the desired reality (Roth, 1987). These prior conceptions are resistant to change and may be glossed over only to reappear. Researchers have found that thinkers can hold alternative conceptions at the same time, selectively utilizing specific forms in specific situations, i.e., school science vs real world science (Osborne & Freyberg, 1985). Meaningful conceptual change takes time and insightful education planning.

Roth (1987) suggested that learning involves children actively extracting information from the environment and constructing personal interpretations and meaning. This process is influenced by the external environment and the learner's prior knowledge and experience. This kind of learning may involve assimilation into existing schema or changing schema to accommodate new experience. This position was consistent with and supported by other research into students' misconceptions, alternative frameworks, and naive theories (Champagne, Gunstone & Klopfer, 1983). Roth's process inevitably leads to the concept of meaningful conceptual change learning and to the subsequent proceduralization of this form of learning into manageable and effective steps, such as those developed by Nussbaum and Novick (1982) in their conceptual change model of instruction, specifically:

1. Initial exposure of students' alternative conceptions through their responses to an 'exposing event';
2. Sharpening student awareness of their own and other students' alternative conceptions through discussion and debate;
3. Creating conceptual conflict by having students attempt to explain a discrepant event; and
4. Encouraging and building cognitive accommodation and the invention of a new conceptual model consistent with the accepted scientific conception.

Posner, Strike, Hewson, and Gertzog (1982) also proposed a model of conceptual change, which proposed four conditions that must be fulfilled if students are likely to make changes in their central concepts by integrating new concepts with existing knowledge:

1. There must be dissatisfaction with existing conceptions,
2. A new conception has to be intelligible,
3. A new conception has to be initially plausible, and
4. A new conception has to be fruitful.

Anderson and Smith (1987) outlined several points to consider when designing problem situations to promote conceptual change, specifically the thinkers and their conceptions must be engaged, they must make prediction of possible outcomes or solutions to the problem, and they must verify their predictions. Again this closely approximates the learning cycle with a prediction phase (Good, et al, 1988) and the hypothetico-deductive inquiry strategy (Yore, 1980). Roth (1987) pointed out that the subsequent development of strategies to get students to construct new links among concepts is most important. What began as a way of constructing a new reality in art, philosophy, and psychology has now become in a method of devising strategies to be used to change students previously constructed concepts of reality and may illustrate important aspects of thinking. The constructivist model has significantly influenced present educational research in reading, mathematics, and science. It has provided, as good models should, a framework that helps explain established patterns while providing potential to resolve emerging patterns. The constructivist model may have equal affect on unifying present conceptions of thinking.

Scientific Inquiry

Scientific inquiry, inquiry learning, and discovery learning have been popular education constructs for over 30 years, but their critical attributes, their similarities, and their differences are not well accepted within the profession (Wilson & Koran, 1976). It is assumed that these constructs have their genesis in the nature, history, and philosophy of science, which has been mediated by the application to education. This transformation into schools has produced related constructs dealing with scientific thinking, scientific literacy, inquiry skills, and scientific heuristics. In fact, what is labelled as scientific inquiry might be better labelled analytical inquiry since it is a form of thinking that transcends academic content areas and school boundaries. The skills and procedures frequently included in scientific inquiry are used in mathematical problem solving, social studies inquiry, reading, speaking, and writing in academic learning as well as in trouble-shooting and decision-making situations outside of formal schools. Munby (1982) stated:

> After all, there is nothing particularly scientific about the idea of comparing things in a way that will reduce the possible inference of other factors. This may sound a little strange, for we seem to be edging towards the view that

there may be nothing special about scientific reasoning that warrants setting it aside from other sorts of reasoning. (p. 15)

It is requisite that a working definition of science be established before proceeding. Science frequently is defined as a body of observable and reproducible knowledge. This conception of science puts too much emphasis on the resulting product of science rather than a balanced emphasis on the process of the scientific enterprise, the people involved in the enterprise, and the product produced by the enterprise. Feyman (1968) defined science as "The belief in the ignorance of experts" (p. 317). This perspective clearly reveals the affective component of science that drives people to question.

Robinson (1965) described science graphically as a cyclic process involving induction and deduction, processes and products which generate ideas, verifies these ideas, and modifies ideas as necessary (figure 3). The ideas may range from simple descriptions, to tentative causal relationships, to overarching explanations (theories). The nature of science demands that these products be viewed as temporary constructions, for new evidence may be used to slightly modify the idea or to reject the idea totally. Robinson's model did not clearly illustrate the theoretic entry into the cyclic process, which could be called mathematical science. Inductive science is based on specific observations being constructed into a unified generalization. Deductive science is based on the application of generalization to predict scientific events. Mathematical science is a theoretical process that suggests the existence of generalizations based on mathematical manipulations, not observations. Some philosophers of science question the existence of inductive science, but interviews with practicing scientists indicate that much induction is used at the problem finding stage of science.

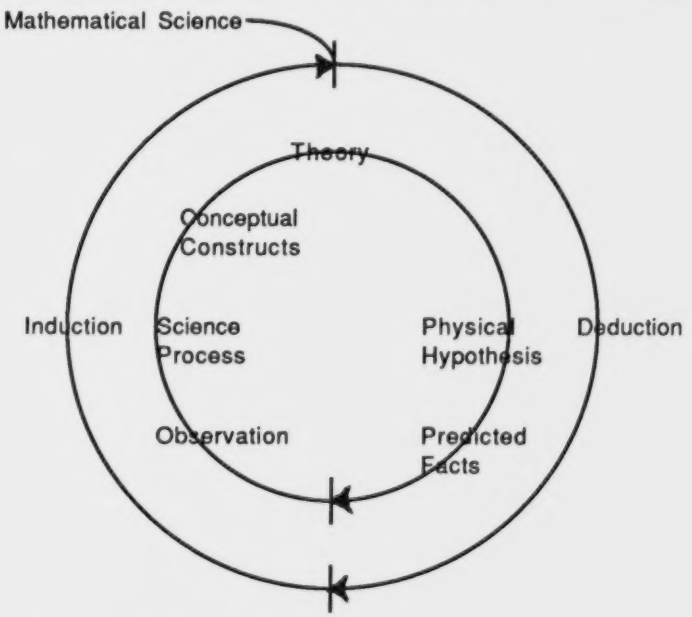

Figure 3: Nature of Science (Adapted from Robinson, 1965)

Yore (1980) defined science as "a human endeavor that attempts to search out, describe and explain patterns of events in the universe" (p. 124). This definition attempts to capture the essence of science as a non-gender people endeavour that was tentative, not always successful, was developmental (searching, describing, and explaining) and was limited by a flexible boundary of the natural universe to patterns (correlational, covariant, and causal relationships). Furthermore, this definition illustrates the unification of science and other disciplines for by substituting quantity, shape, and numerals; culture, family, and society; or symbols and language for "events in the universe", one could be defining mathematics, social studies, or language arts.

Shymansky and Yore (1980) further described science as being cyclic and self-verifying, utilizing both induction and deduction, and process and product. Munby (1982) stated

> "what seems to have been missed [in science teaching] is that theories or models are not right or wrong but of variable usefulness ... If teachers and texts in schools continually made it clear that models and theories of increasing complexity are generated to deal with increasingly diverse and complicated observation, the students...would be prepared to anticipate novel and more refined model. (p. 24)

NSTA (1964) provides five assumptions underlying the nature of science that more fully define or describe the scientific enterprise.

1. Science proceeds on the assumption, based on centuries of experience, that the universe is not capricious.
2. Scientific knowledge is based on observations of samples of matter that are accessible to public investigation in contrast to purely private inspection.
3. Science proceeds in a piecemeal manner, even though it also aims at achieving a systematic and comprehensive understanding of various sectors or aspects of nature.
4. Science is not, and will probably never be, a finished enterprise, and there remains very much more to be discovered about how things in the universe behave and how they are interrelated.
5. Measurement is an important feature of most branches of modern science because the formulation as well as the establishment of laws are facilitated through the development of quantitative distinctions.

It is clear that science is a process that leads to the construction of ideas that people believe describe and explain things within the capabilities of human beings' understanding. People must realize that science does not map reality to understanding on a one-to-one basis but rather provides a collective construction of a dynamic temporary image of reality (Nadeau & De'sautels, 1984).

Based on the above description of science, the term inquiry has come to mean three different things such as:

> the logical process, the method used in the subject field. ...the thinking, divergent thinking, problem solving [emphasizing] the learner, ...[or the] method of teaching [involving the] interaction of the student, the teacher and the subject matter. (Connelly, Finegold, Chipsham & Wahlstrom, 1977, p. 5)

Kyle (1980) believed that the confusion between these terms has resulted in fuzzy thinking within the education community and is a poor foundation for students of the 21st century.

Schwab (1964) pointed out that inquiry can result in the production of new knowledge or the development of experimental techniques. Schwab's stable inquiry is designed to acquire new knowledge and to fill in existing knowledge gaps or assimilation of new ideas into existing schema. Stable inquiry is influenced by existing knowledge. If stable inquiry produces descrepant knowledge regarding the existing knowledge structures and assumptions, the inquiry is converted into fluid inquiry. Fluid inquiry's goal is not to add knowledge to existing structure but rather to produce new ways of thinking about the old structure. Fluid inquiry frequently involves restructing or reconstruction of long held conceptions similar to accommodation process.

Dewey (1938) stated:

> The search for pattern of inquiry is not one instituted in the dark or at large. It is checked and controlled by knowledge of the kinds of inquiry that have and that have not worked; methods which, as was pointed out earlier, can be so compared as to yield reasoned or rational conclusions. For, through comparison-contrast, we ascertain how and why certain means and agencies have provided warrantably assertible conclusions, while others have not and cannot do so in the sense in which 'cannot' expresses an intrinsic incompatibility between means used and consequences attained. (p. 104)

Dewey stressed the importance of the thinking embedded in inquiry, the need for prior knowledge, the need to sort out productive heuristics from less productive heuristics, and soundness of the linkage or association between evidence, warrants, and conclusion. Roberts' (1982) analysis of the logic, evidences, warrants, and limitations of qualitative and quantitative science education research is helpful in clarifying Dewey's last point. Dewey (1938) summarized his beliefs with:

> Inquiry is the controlled or directed transformation of an indeterminate situation into one that is so determinate in its constituent distinctions and relations as to convert the elements of the original situation into a unified whole. (pp. 104-105)

He further specified that scientific inquiry differs from common sense inquiry in respect to:

> ... subject matter, not in their basic logical forms and relations; that the difference in subject matter is due to the difference in the problems respectively involved, and, finally, that this difference sets up a difference in the ends of objective consequences they are concerned to achieve. (pp. 114-115)

Generally, common-sense inquiry produces a practical system of knowledge where scientific inquiry need not produce practical knowledge. Currently the difference between common-sense and scientific inquiries have faded, with the realization that science, technology and society (STS) interact on several levels. Societal needs frequently drive technological inquiry, which results in new

inventions as well as new science, and is in stark contrast to the traditional view that science drives technology, or that science, technology and society are isolated independent operations. Risi (1982) pointed out that "technological innovation is the process by which an idea or an innovation that fills a [potential or existing] need is introduced into the economy so as to generate economic growth, exports and jobs" (p. 12). He further suggested that the thinking that will drive 21st century innovations will need to be trans-disciplinary. The problems presently being faced by North American society are multi-dimensional, involving several traditional science disciplines and non-science disciplines. Even within the science community the hybrid sciences of biochemistry, biophysics, geochemistry, and geophysics are some of the most exciting areas today. Future STS issues will require thinkers well versed in trans-disciplinary concepts, skills, values, and attitudes.

Dewey also pointed out that inquiry stimulates inquiry. He believed that the products of one inquiry generated conceptual foundations and problematic situations for future inquiries. Each subsequent inquiry "brings into high relief conditions previously obscure and relegate to the background other aspects that were at the outset conspicuous" (Dewey, 1938, p. 117). Kyle (1980) defined scientific inquiry:

> As a systematic and investigative performance ability which incorporates unrestrained inductive thinking capabilities after a person has acquired a broad and critical knowledge of the particular subject matter through formal learning processes. (p. 123)

Scientists frequently indicate that they utilize inductive inquiry to find and clarify problems, but generally formulate hypotheses to guide the following investigations. Kyle's definition clearly couples effective scientific inquiry to prior knowledge about the problem area and prior knowledge about the inquiry process. The influence of prior knowledge illustrates the metacognitive component of scientific inquiry. Newton (1970), and Stone, Geis, and Kuslan (1971) confirmed the interactive links between inquiry, questioning, collecting evidence, detecting patterns, and verifying patterns. Newton described inquiry as a process of messing around with objects, events, and ideas to detect patterns, check consistencies, and verify predictions. Stone, Geis, and Kuslan suggested inquiry was a process of asking questions, collecting information, and asking additional questions that develop more complete understanding or formulate more acute investigations.

Regardless of the cluster of attributes used to describe scientific inquiry, little support can be found for the traditional lock-step scientific method frequently associated with science. Boyd (1972) illustrated a more realistic view of inquiry by suggesting that inquiry has some common component parts but how these parts are assembled must fit the problem situation and the person doing the inquiry. Figure 4 illustrates the multi-pathways in scientific inquiry. The specific pathway or heuristic will be the product of the investigator's prior knowledge, problem context, and established background.

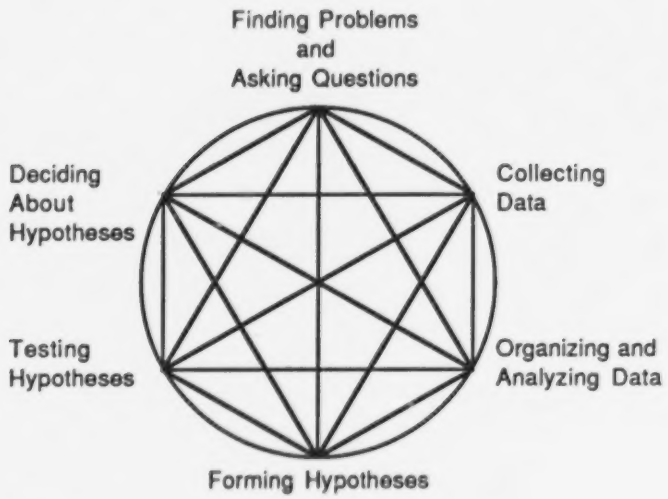

Figure 4: Scientific Inquiry (Adapted from Boyd, 1972)

Morine and Morine (1973) outlined six inquiry modes reflecting much of the nature of scientific inquiry. Their conception of inquiry is interesting, but generally the modes fit into inductive inquiry, deductive inquiry, and hypothetico-deductive inquiry categories. The inductive model requires specific science process and inductive synthesis to establish generalized concepts. The traditional deductive inquiry involves the application of an investigation to verify a generalization. The hypothetico-deductive inquiry is hypothesis-driven inquiry in which predictions are made on the assertions that the hypothesis is true or that the hypothesis is false. These predictions are later compared to specific evidence, and a decision to support, to reject totally or to reject and revise is made. Morine and Morine also outlined a transductive inquiry designed to promote creativity, divergent thinking, and multiple solutions. Each of these inquiry modes places specific demands on the thinkers' prior declarative knowledge, procedural knowledge, conditional knowledge, self-management skills, and cognitive skills.

Munby (1982) and Roberts (1983) outlined the scientific thinking and scientific literacy resulting from and embedded in the scientific enterprise. Munby suggested that the microscopic thinking skills are clustered under an umbrella of reasoned judgment. He suggested that accessing of information, assessing the quality of information, and structuring of logical arguments were essential to reasoned judgment. Munby also pointed out that much of scientific thinking is trans-disciplinary and many of "the fallacies are tied to rules of reasoning that are not dependent upon context" (p. 17). Furthermore "science...is as dependent upon critical thinking as are literature, history and musiology" (p. 18). Roberts expanded the conception of reasoned judgment with the formation of

informed science opinion and the ability to communicate these opinions to others as critical components of scientific literacy. Roberts appeared to suggest that scientific literacy involves knowing how knowledge is constructed, learning how to learn, and being able to transmit the knowledge to others. Both Munby and Roberts appear to support the conceptual unity of scientific inquiry, scientific thinking, and scientific literacy with other areas of thinking, metacognition, and constructivist model.

Kuhn, et al (1988) stated the "implementation of this goal (thinking), however, has been constrained by the very limited body of research data identifying the specific nature of such skills" (p. 3). They suggested a central premise underlying science is that scientific theories relate facts and concepts into a unified causal understanding that can provide global explanations and predict unobserved events. The "skillful coordination of theory and evidence entails a complex interplay. While existing theories provide the basis for interpretation of new information, new information ideally is attended to and utilized as a basis for evaluating and revising theories. Skillful coordination of theory and evidence also entails a high degree of metacognitive function, that is, reflection on one's own cognition" (Kuhn, et al, 1988, p. 3). They also suggested that thinking with different labels involved equal cognitive demand and evidence conclusion analysis. Kuhn, et al outlined a parallel between inquiry and how children construct theories of reality when children attempt to modify discrepant evidence observed. They caution that children are notoriously weak on metacognitive reflection during this revision process. The proficient scientific thinker is a person who is aware of and reflects on theories, can formulate alternative theories, can compare/contrast competing theories, and can evaluate competing theories in light of existing evidence. This thinking involves the integrated use of scientific processes, different cognitive skill levels, inductive and deductive logic, an established knowledge base, and appropriate attitudes, emotional dispositions, and values.

Scientific thinking, like thinking in other areas, is a process in which evidence is collected, analyzed, generalized, and verified. The degree to which a person's emotions are involved in the interpretation of this evidence may vary between the disciplines but the intellectual processes appear to be common.

SUMMARY

The purpose of this symposium was to encourage the exploration of a unified conception of thinking that will reverse the fragmentation of thinking skills, that would incorporate a trans-disciplinary perspective, and that would integrate academic and real-life situations. Sternberg and Martin (1988) stated that:

> Virtually no problems we encounter in our everyday lives are solvable through the application of just a single thinking process or skill. Rather, they require a combination of processes and skills, and indeed, much of the difficulty of typical problems inheres in knowing how to combine the appropriate processes and skills. In other words, the putting together of the parts for solution is every bit as challenging as the use of the parts in and of themselves. (pp. 566-567)

The Task Force on Thinking (New Jersey Basic Skills Council, 1986) explored many of the issues central to this symposium. The committee found that educational institutions promote thinking that is more abstract, critical, systematic, and precise than thinking found in non-school environments; that schools will need to emphasize thinking which promotes academic performance, economic performance, and effective citizenship; and that thinking can be effectively taught. The committee produced the following:

1. Recommendations for Those Who Make Educational Policy

A. Effective instruction in thinking skills will require a high priority, coordinated effort; piecemeal efforts will fail.
B. Effective instruction in thinking skills will require teachers who self consciously practice those skills and teach them by example, who are trained and rewarded for teaching them, and who are sufficiently current in their own content and sufficiently confident of their own content mastery, to manage some of the more exploratory methods necessary to thinking-oriented instruction.
C. Instruction in thinking skills should extend across all grade levels; it should begin in elementary school and permeate education at all succeeding levels.
D. Instruction in thinking skills should extend across all subject areas; thinking skills should be taught primarily by changing the way in which all content materials are taught and not by isolated courses on thinking.

2. Recommendations for Those Who Construct or Select Instructional Materials

A. Instructional programs which provide substantial amounts of work on 'convergent' thinking (understanding the relationships among ideas)are preferable to programs which focus heavily or exclusively on 'divergent' or 'creative' thinking (generating large numbers of different ideas).
B. Holistic approaches, in which students practice the entire thinking process, are preferable to atomized approaches, in which they receive intensive practice on specific components of that process.
C. Holistic, thinking-oriented instruction in math and science should involve practice in discovering patterns, defining problems worthy of investigation, and collecting and evaluating data on those problems -- in addition to the traditional drill on solving set problems.
D. Holistic, thinking-oriented instruction in the humanities and social sciences should similarly involve practice in defining questions worthy of investigation, the collection and evaluation of data on those questions, and the formulation and written presentation of the

students' own viewpoints -- in addition to the traditional practice of analyzing the viewpoints of others.

3. Recommendations for Classroom Teachers

A. Motivating students to undertake the demanding task of thinking abstractly, critically, and systematically will require not only pedagogy which permits such activity, but also instructional approaches and reward systems which require it, continuously.
B. Thinking-oriented instruction in the inductive areas of listening, observing, and reading, should require students to transform new information (e.g., by paraphrasing, summarizing, outlining, etc.), rather than simply committing it to memory in its original form, and should require students to relate that new information directly to their existing knowledge and preconceptions.
C. Thinking-oriented instruction in the area of creativity should be rooted in a secure knowledge base, rather than being taught in the abstract, and should require students to review systematically a variety of approaches to questions before settling on any one approach.
D. Thinking-oriented instruction in the deductive areas of constructing and evaluating hypotheses and arguments, and indeed in all of the above elements of the thinking process, should require students to develop, explain, and defend their points of view in open discussion with their teachers and each other, and, ultimately, to subject those views to the discipline of precise written expression. (pp. vii-viii)

Considerable thinking about thinking is required to improve instruction of thinking. Continued efforts like the New Jersey Basic Skill Council's report, Ontario's thinking across the curriculum and British Columbia's present search are needed. The contributions of science education programs like SCIS, SAPA and ESS need to be reviewed and new research efforts must be encouraged. This symposium is just a start.

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